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(54) High power density regenerative fuelcell for peak power.

(57) Low capacity and high power density electric fuel cell which electrolyzes water in the charging phase to produce hydrogen and oxygen used, as reactants in the discharging phase, which fuel cell (2) comprises an ion-exchange membrane (3), separating two compartments, said compartments containing gas evolving positive (11) and negative electrodes (7) respectively for the evolution of oxygen and hydrogen during the charging phase and for recombination of the same to produce water during the discharging phase, as well as means for the circulation of said water in a spray form.

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## HIGH POWER DENSITY BATTERY FOR PEAK POWER

### BACKGROUND OF THE INVENTION

The present invention concerns a low capacity and high power density battery apt to supply high power output for short periods of time and therefore particularly suitable as a back-up to a steady-output generator, for electric vehicles in the urban traffic.

Electric traction is considered a possible solution to the problems of air and noise pollution. Two lines of development have been pursued so far, the first one resulting in some practical applications in the field of public vehicles (mail and milk distribution, warehouse fork-lifts etc.), provided with an electric battery which is recharged at the end of the day. Presently, lead batteries with a specific energy density of 20-30 Wh/kg ensure a range of operation (an autonomy distance span) of 100/200 km, but weight, even for the so-called "Iron-clad" types, is a serious drawback especially in town traffic where the acceleration necessary to cope with the dynamics of the traffic involves significant power outputs. Many solutions have been tested in an effort to optimize the autonomy-weight-power relationship but without effective results.

Attempts have been made also in the field of light batteries, zinc-air for instance, which even when reaching high energy densities, up to 100 Wh/kg, did not overcome certain technological barriers.

Another line of development, which has been worked out during the middle of the 50's, is based on a fuel cell fed, in the most recent embodiments, with air (positive electrode) and a mixture of H<sub>2</sub> - CO<sub>2</sub> (negative electrode), such a mixture being obtained from a methanol reformer integrated with the fuel cell.

The recent introduction of fluorinated ion exchange membranes offering a high conductivity (G.A. Eisman -Symposium on Diaphragms, Separators and Ion Exchange Membrane - Electrochemical Society proceeding Vol. 86-13 page 156) got closer to the target and, at the same time, emphasized the irrationality of combining a generator system made of a fuel cell plus reformer, (rather rigid as it requires operation at steady load) with an application, the electric vehicle, which in the urban traffic needs peak power outputs during the accelerations but for a good part of the remaining time (deceleration, stops, etc.) it requires a modest or even zero power output.

In order to interface the generator system (battery or fuel cell) with the end-use system (electric vehicle), a hybrid system, battery/battery

or fuel cell/battery, has been proposed, where a back-up battery is aimed to supply for short periods the peak power outputs required for the acceleration, while a steady-output generator supplies sufficient energy for the normal operating conditions, while recharging the battery during stops and even during the operation with the unexploited exceeding power.

This concept has already been developed combining a membrane fuel cell to a nickel-cadmium battery or, in alternative to a zinc-air battery, as proposed by the Japanese MITI program for a hybrid acid lead-zinc air batteries system. A different solution may be the development of nickel-metal hydrides batteries as recently proposed with interesting but not so satisfactory results to solve the problems of interfacing the generator to the energy requirements of an electric vehicle (H. Ogawa, M. Ikoma, K. Kawano and I. Matsumoto - Preprint No. 28 of the 16th International Power Source Symposium-1988).

### THE INVENTION

It is an object of the present invention to provide for an electric battery directed to supply, for short periods of time, high energy outputs, and therefore suitable to meet the typical peak power requirements of an electric vehicle.

It is a further object of the present invention to provide for a battery with a reduced weight as to be advantageously used on board of vehicles and in general of transport means.

A further object is to provide for a battery which can be advantageously used as a back-up battery in an electricity generating system of an electric vehicle particularly suitable for the town traffic, which system is made of a back-up battery and a steady-output generator, this last one consisting of a battery or fuel cell integrated with a methanol-fed reformer.

The present invention regards a back-up/steady state output generators system apt to drive an electric vehicle for the town traffic involving a peak power absorption (typically 30-200 kW) for some tenths of seconds (typically 30 secs) representing 17% of the total acceleration-cruise-deceleration-stop cycle, an absorption of 25% of the full load for the cruise period lasting some minutes (typically 2 minutes) and representing 66% of the total cycle and almost zero absorption for the deceleration and stop periods for about 30 seconds - one minute representing in the average

17% of the total cycle.

Assuming the steady output generator be working at constant current density, its nominal power  $P_n$  referred to the maximum available power ( $P_{max}$ ) results to be

$$P_n = (P_{max} \times 17 + 0,25 P_{max} \times 66)/100 = 0,335 \times P_{max}$$

hence the power required for the back-up battery,  $P(b.u.)$  is :

$$P(b.u.) = 0,665 P_{max}$$

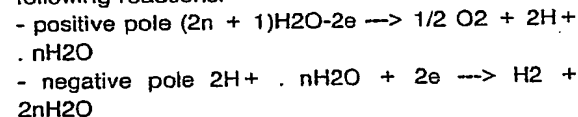
It is clear that the back-up battery allows to reduce the steady-output generator power (e.g. fuel cell plus reformer) to one third of the peak.

Moreover, the back-up battery can absorb high current densities also during the charging phase and can recover the deceleration energy.

As regards the components of the system, the present invention refers to an electric battery having low capacity and high current density where, in the charging phase, water is electrolyzed with the production of hydrogen and oxygen stored in the negative and positive pole compartments of the battery, to be used as reactants during the discharging phase.

The battery comprises a polymeric membrane having a proton conductivity, electrocatalyst material embedded on the two sides of the membrane and two compartments, (negative and positive poles) where the electrolysis gases are stored.

As explained before, the battery acts as an electrolyzer in the charging phase involving the following reactions:

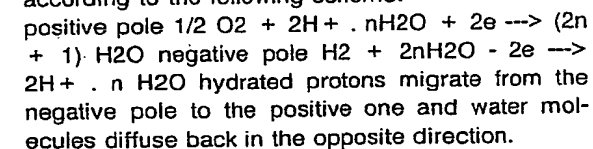


In addition the hydrated protons  $H + nH_2O$  migrate in the membrane from the positive pole to the negative one.

The hydration,  $n$ , is in the order of three to four water molecules for each proton.

At the same time, water migrates back through the membrane, (from the negative pole to the positive one) so that the net transport of water in the membrane is negligible, provided that the membrane is allowed to keep the correct water, which also ensures the electric conductivity necessary for the hydrated protons migration.

During the discharging phase where the preceding reactions take place in the opposite way, according to the following scheme:



In the electrochemical systems with a solid polymeric electrolyte and SPE(R) gas electrodes,

that is electrodes in form of catalytic powder bound to both faces of the membrane, so that no liquid electrolyte is needed, problems arise for the water management directed to supply and to remove reaction water in the positive and negative poles compartments and to assure the correct hydration of the ionic polymeric membrane. This can be obtained keeping the membrane in contact with a gas where the partial pressure of water is slightly over or below, according to the necessities, to the water vapor pressure of the ionic membrane, at the various temperatures.

The present invention will be better illustrated in the following detailed description. It is however evident that different embodiments are possible without departing from the scope of the present invention.

Referring to the drawings:

Figure 1 is a cross-section of a single element of a membrane hydrogen-air battery.

Figure 2 is a schematic view of the steady output generator plus reformer.

## DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates an embodiment of the present invention comprising a single element of a membrane hydrogen oxygen battery, wherein two rigid end plates 1 and 2 equipped with external cooling fins (not shown in figure) are separated by a polymeric ion-exchange membrane 3 sealed by flanges 4 to form a negative pole compartment comprising a rigid structure 5 supporting a small opening mesh 6 which presses against the membrane a thin layer of electrocatalytic material 7 and a positive pole compartment having half the volume of the negative pole compartment and comprising a rigid structure 8 on which a resilient mattress 9, for example as described in DE-A- 30 28 970, is positioned and presses, by means of a small-opening mesh 10, the thin layer of electrocatalytic material 11 against the membrane and the membrane itself against the rigid structure of the negative pole compartment. The rigid structure 8, the metallic mattress 9, the mesh 10 provide for electric current flow between the electrode material 11 and the end plate 2 which is used for the electrical connection within the stack of elements which form the battery. If the battery has to store gas up to reach high pressures at full charge, the whole battery can be inserted in a metal or fiberglass-reinforced plastic pipe, and the empty space between the battery and the pipe is filled with a dielectric liquid which assures the electric insulation among the various elements, the balancing of the inside/outside pressures and the elimination of the heat dispersed

through the cooling fins on end plates 1 and 2.

In the resilient metallic mattress 9 hydrophilic fibers or the like are interwoven. During the charging step, the hydrophilic fibers absorb water which is present as a spray in the gas phase and allow an easier supply of the reaction water ( $\text{H}_2\text{O}-2\text{e} \rightarrow \frac{1}{2} \text{O}_2 + 2\text{H}^+$ ) to the electrocatalytic material 11. During the discharging step, the fibers absorb by capillarity the reaction water ( $\frac{1}{2} \text{O}_2 + 2\text{H}^+ + 2\text{e} \rightarrow \text{H}_2\text{O}$ ) formed on the surface of the electrocatalytic material 11 and make the drain easier towards the bottom of end plate 2 preventing flooding of electrocatalytic material 11. On the bottom of end plate 1 a groove 12 is provided which contains deionized water used to humidify the hydrogen gas by means of a high frequency sprayer 13. On the bottom of end-plate 2, a groove 14 is also provided, which contains the reaction water necessary for the charging step: a high frequency sprayer 15 directs the small water droplets upwards to be absorbed by the hygroscopic fibres interwoven in mattress 9 during the charging step. The same groove 14 collects the water formed during the discharging step and stores it for the next charging step. Two pipes 16 and 17 placed on the bottom of 1 and, respectively, 2 have a double purpose. The first one is to effect the first water load in 12 and, respectively, 14. The other one is to eliminate the air contained in 1 and 2 at the moment of the first charging step, in order to avoid dilution of hydrogen and oxygen with the atmospheric nitrogen.

For an energy production corresponding to 20 kW/m<sup>2</sup> supplied for a period of 5 minutes to the pressure, at full charge, of 10<sup>7</sup> Pa, the negative pole compartment should have a 9 litre volume useful for storing hydrogen with a corresponding 4-5 litre volume useful for storing of oxygen in the positive pole compartment. The total volume of the battery results to be 40 litres with a weight of 100 Kg including fittings and piping for pressure operation. This leads to a 17 Wh/kg energy density, to 25 Ah/kg capacity and 0,2 kW/kg power density. At each charge and discharge 702 g of water are consumed or released into the positive pole compartment.

Besides a high frequency sprayer, the spraying of water in the negative pole and, above all, in the positive pole compartments can be carried out with an airless nozzle which sprays pressurized water coming from outside the battery through a piping system not shown in figure 1. The water, collected in channels 12 and 14, is removed by means of pipes 16 and 17.

Preferably a high frequency sprayer is used to humidify hydrogen of the negative pole compartment and a spraying nozzle with pressurized water to supply the positive pole compartment with water.

Fig. 2 shows a different embodiment of the

present invention particularly suitable when the steady-state output generator is an air-hydrogen fuel cell working at 80-90 °C and integrated with a reformer. Hydrogen is stored outside the battery, whereas oxygen is wasted to the atmosphere and the battery operates with air, like the fuel cell to which it is coupled.

The battery has the same structure of the battery in figure 1 (numerals from 1 to 17) with the only exception of the metallic mattress 9 being in the negative pole compartment. The positive pole compartment is connected to the air compressor 18. The compressed air is fed to the sprayer 19, enters into the positive pole compartment through 20, leaves such compartment from 21, and after expansion in 22, is vented in the atmosphere through 23. In the discharging step with water formation in the positive pole compartment, the dry and hot air, supplied by compressor 18, evaporates the reaction water, driving it away through 22 and 23. During the charging step the sprayer 19 is fed with water from the tank 24 which drains, by means of 25, the bottom of 1. A dosing pump 26 feeds to 19 the quantity of water to be sprayed according to the operating conditions the battery is run. The compressor and the turbine, driven by the electric engine 27, are coaxially connected in order to allow the recovery of the compression energy.

In the negative pole compartment, end-plate 1 is provided with openings 28 and 29 for the inlet and outlet of the hydrogen stored in tank 30 and kept in circulation by means of pump 31. Sprayer 32 receives water from the tank 33 through the dosing pump 34. Pipe 35 drains the water which is collected in the bottom of the negative pole compartment and is conveyed into tank 33.

Whenever the back-up battery is combined with a steady-state output fuel cell operating with air and hydrogen, the air circuits of the battery and of the fuel cell may be common and both the battery and the fuel cell are kept at the same temperature. The steady state output fuel cell comprises similar devices as under the back-up battery for the humidification of the gas flows by spraying of water, as well as a common compressor and air turbine, high frequency generator for the sprayer and pump of the pressure water.

The electric interfacing between the steady-state output battery and the back-up battery can be carried out by dividing the back-up battery into sections to be series or parallel connected during the charging and discharging. If the electric vehicle is equipped with AC motors, the interfacing can be done using the same inverter which feeds AC energy to the motor.

## Claims

1. Low capacity and high power density electric battery which comprises at least one electrode chamber formed by two end-plates (1, 2) and separated by an ion-exchange membrane (3) into a positive pole compartment and a negative pole compartment,

a positive electrode (11) in contact with one side of said membrane (3) and a negative electrode (7) in contact with the other side of said membrane (3), the electrodes being suited for the evolution and storage of oxygen and hydrogen during the charging phase and for the recombination thereof to produce water during the discharging phase, means for supplying water to and discharging water from said compartments,

means for supplying oxygen to one compartment and for supplying hydrogen to the other compartment

and means for discharging oxygen and hydrogen from said compartments.

2. The battery of claim 1, wherein each electrode (7, 11) is a thin layer of a powdered electrocatalytic material.

3. The battery of claim 2, wherein the electrodes (7, 11) are bonded to or embedded into the membrane (3).

4. The battery of claims 1 or 2, wherein the electrodes (7, 11) are pressed against the membrane (3) by supporting means.

5. The battery of claim 4, wherein the supporting means supporting the negative electrode (7) is a rigid structure (5) carrying a small opening mesh (6) and the supporting means supporting the positive electrodes (11) is a rigid structure (8) carrying a resilient mat (9).

6. The battery of claim 5, wherein the resilient mat (9) comprises a hydrophilic material, in particular hydrophilic fibres.

7. The battery of anyone of claims 1 to 6, wherein the means for supplying water into said compartments are spraying means (13, 15).

8. The battery of claim 7, wherein the spraying means (13) for the negative pole compartment is a high frequency sprayer and the spraying means (15) for the positive pole compartment is an airless nozzle.

9. The battery of anyone of claims 1 to 8, characterized in that the positive pole and negative pole compartments are able to withstand a pressure up to  $10^7$  Pa.

10. The battery of anyone of claims 1 to 9, characterized in that said battery is contained in a pressure-resistant vessel, the space between said battery and the walls of said vessel being filled with dielectric fluid.

11. Generator system for driving an electric vehicle comprising an electric battery as defined in anyone

of claims 1 to 8 and a steady power output generator.

12. The generator of claim 9, wherein the steady power output generator is a battery or fuel cell with a methanol fed reformer.

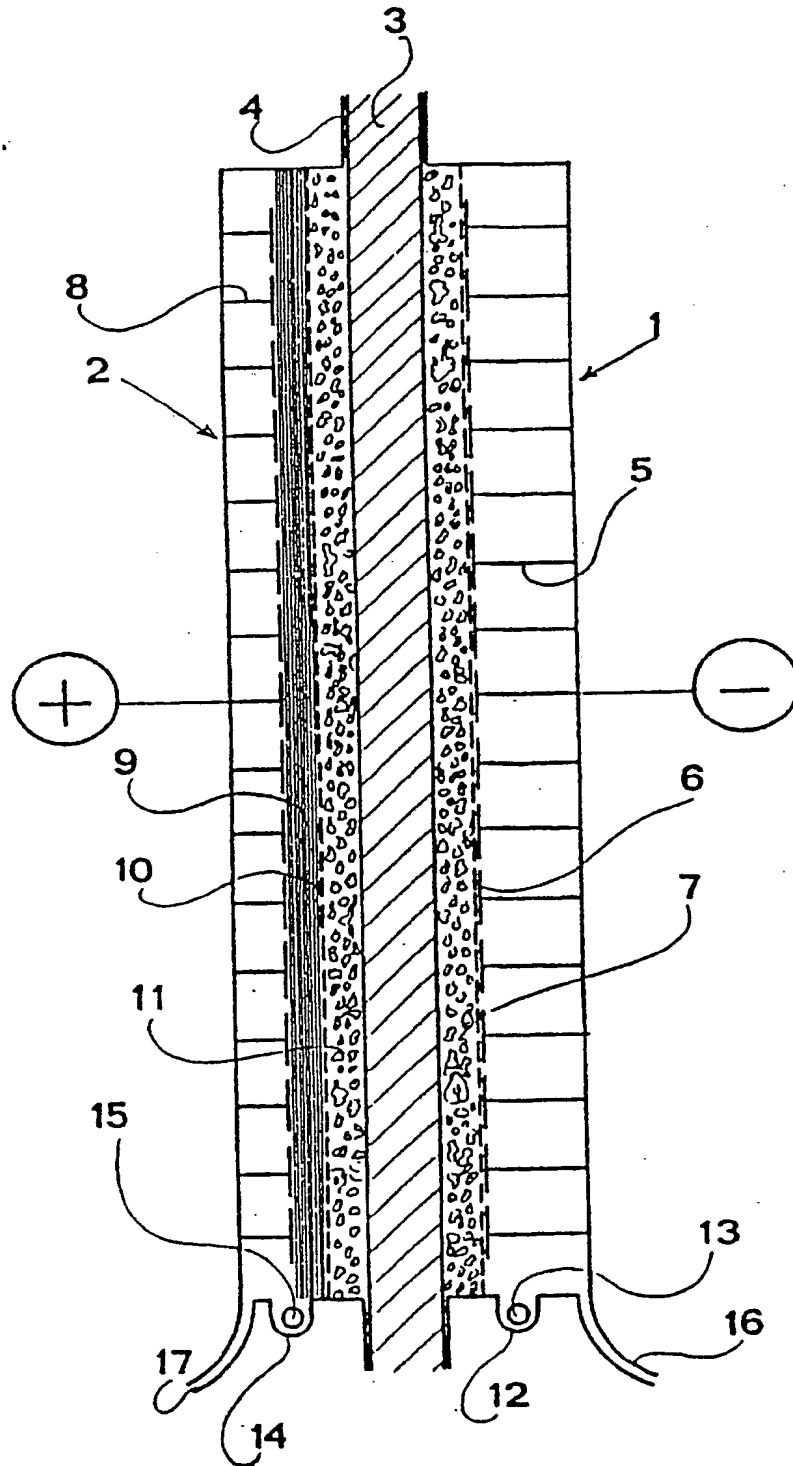


FIG.1

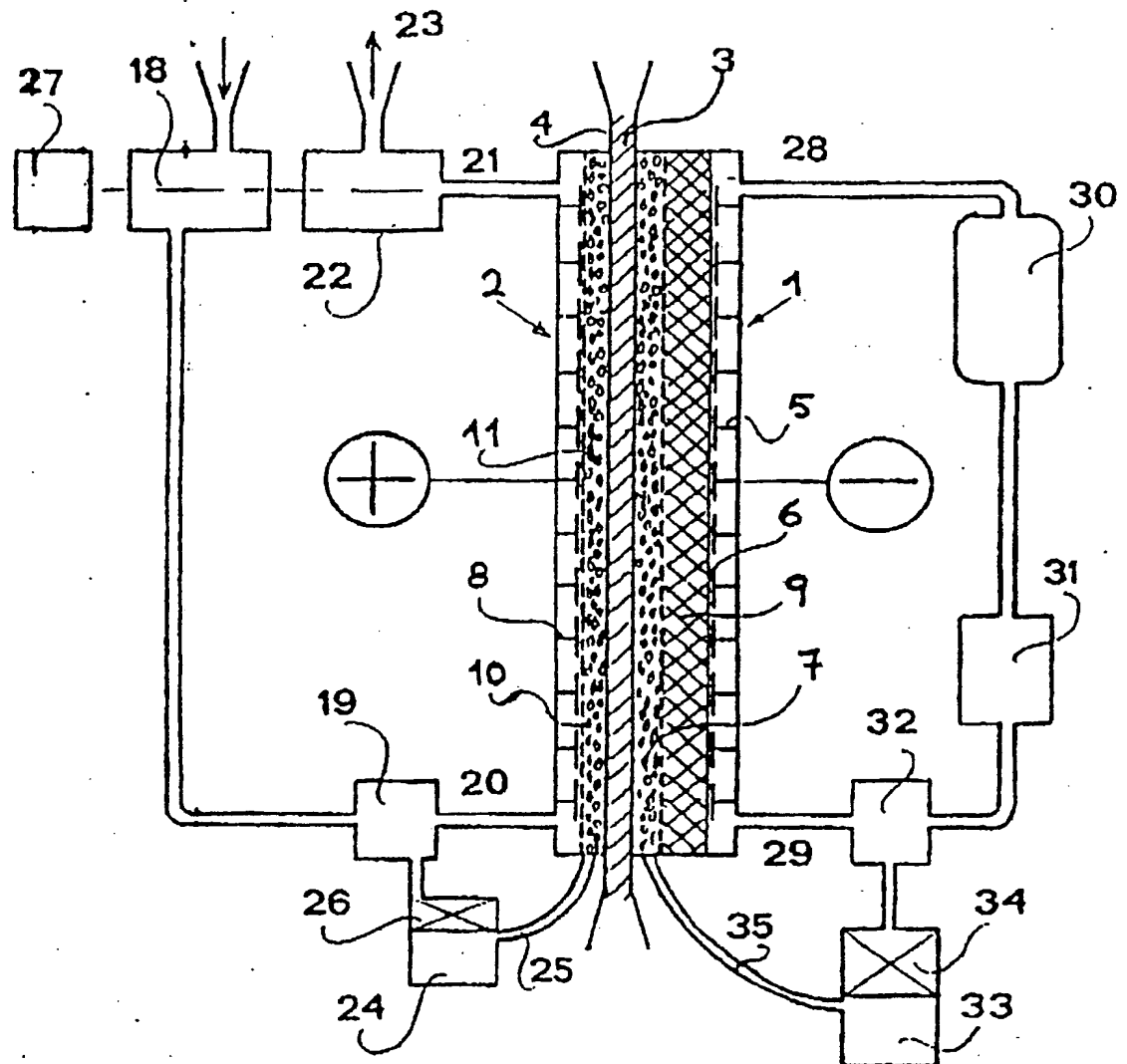


FIG. 2



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# EUROPEAN SEARCH REPORT

Application Number

EP 90 11 2768

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	PATENT ABSTRACTS OF JAPAN, vol. 9, no. 15 (E-291)[1738], 22nd January 1985; & JP-A-59 163 770 (NIHON DENCHI K.K.) 14-09-1984 * Abstract *	1,2,3	H 01 M 8/18 H 01 M 16/00
Y	IDEM	5,6,7, 10,11, 12	
X	US-A-3 134 697 (L.W. NIEDRACH) * Example 10; column 16, lines 13-19; column 5, lines 3-40; claim 8 *	1,2,3,4	
Y		5,6,7, 10,11, 12	
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Y	PATENT ABSTRACTS OF JAPAN, vol. 13, no. 179 (C-590), 26th April 1989; & JP-A-1 008 286 (MITSUBISHI HEAVY IND.) 12-01-1989 * Abstract *	5,6	TECHNICAL FIELDS SEARCHED (Int. Cl.5)  H 01 M
Y	EP-A-0 316 626 (DORNIER GmbH) * Claims 1,2,6,7,8; column 2, lines 45-47; column 3, lines 23-28; column 4, lines 48-51 *	7	
Y	FR-A-2 225 539 (TOKUYAMA SODA K.K.) * Figure 2; claim 9; example 1; page 1, lines 29-31 *	7	
		-/-	
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 15-10-1990	Examiner D'HONDT J.W.
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document	





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DOCUMENTS CONSIDERED TO BE RELEVANT			
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Y	PATENT ABSTRACTS OF JAPAN, vol. 11, no. 257 (E-534)[2704], 20th August 1987; & JP-A-62 66 581 (HITACHI LTD) 26-03-1987 * Abstract *	10	
X	SAE TRANSACTIONS, vol. 70, 1962, pages 398-407, Soc. of Automotive Engineers, New York, US; R.H. BLACKMER et al.: "Ion exchange membrane fuel cell for space vehicle electric power" * Page 399, right-hand column, paragraph 1; figure 1c *	1	
A	US-A-3 418 168 (E.L. WENTWORTH)		
A	PATENT ABSTRACTS OF JAPAN, vol. 13, no. 396 (E-815)[3744], 4th September 1989; & JP-A-1 143 154 (ISHIKAWAJIMA HARIMA HEAVY IND. CO., LTD) 05-06-1989		
A	US-A-3 546 020 (C. BERGER) * Column 8, lines 26-49; figure 6 *	1	
X	PATENT ABSTRACTS OF JAPAN, vol. 11, no. 212 (E-522)[2659], 9th July 1987; & JP-A-62 35 463 (MITSUBISHI HEAVY IND. LTD) 16-02-1987 * Abstract *	1	TECHNICAL FIELDS SEARCHED (Int. Cl.5)
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 15-10-1990	Examiner D'HONDT J.W.
<b>CATEGORY OF CITED DOCUMENTS</b> X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons * : member of the same patent family, corresponding document			

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